AFRL-HE-WP-TR-2005-0102

AIR FORCE RESEARCH LABORATORY

The Visual-Acuity-Based, Night Vision Goggle Cockpit Lighting Compatibility Field Evaluation Test Kit: A Low-Cost Alternative

Alan R. Pinkus

Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433-7022

Harry L. Task

Task Consulting
5513 Snowbank Circle
Dayton OH 45431-2813

Martha A. Hausmann
Maryann H. Barbato

General Dynamics Co.
Advanced Information Engineering Services
5200 Springfield Pike
Dayton OH 45431-1289

Interim Report For The Period October 2003 To September 2004

May 2005

Human Effectiveness Directorate
Warfighter Interface Division
Wright-Patterson AFB OH 45433

NOTICES

TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TR-2005-0102

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

//Signed//

MARIS M. VIKMANIS
Chief, Warfighter Interface Division
Air Force Research Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
May 2005

3. REPORT TYPE AND DATES COVERED
INTERIM (Oct 2003 to Sep 2004)

4. TITLE AND SUBTITLE
The Visual-Acuity-Based, Night Vision Goggle Cockpit Lighting Compatibility Field Evaluation Test Kit; A Low-Cost Alternative

5. FUNDING NUMBERS
PR: 7184
TA: 11
WU: 27

6. AUTHOR(S)
Alan R. Pinkus, *Harry L. Task, **Martha A. Hausmann, and **Maryann H. Barbato

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
* Task Consulting, 5513 Snowbank Cir, Dayton OH 45431-2813
** General Dynamics Co., Advanced Information Engineering Services
5200 Springfield Pike, Dayton OH 45431-1289

8. PERFORMING ORGANIZATION
AFRL/HECV

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Air Force Materiel Command
Wright-Patterson AFB OH 45433-7022

10. SPONSORING/MONITORING
AFRL-HE-WP-TR-2005-0102

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distibution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Cockpit lighting can interfere with the proper operation of night vision goggles (NVGs) in several specific ways. For each interference mechanism, the effect on the image seen through the NVGs is to reduce the brightness of portions of the image and/or reduce the contrast of the useful image (the view outside the aircraft). This reduction in brightness or contrast may be manifested as a reduction in visual acuity and/or as an observed loss of contrast or brightness. AFRL/HECV was requested by the FAA (this research effort was jointly funded by the FAA and AFRL/HECV) to investigate low-cost, alternative methodologies that can be used by civil aviation to evaluate NVG cockpit lighting compatibility. In order to facilitate the inexpensive evaluation of cockpit lighting interference with the operation of the NVGs, a field evaluation kit was developed. This kit makes it possible to conduct a low-cost version of the standard visual acuity test method currently used by the Air Force. This report describes the fabrication, components, and implementation of this field evaluation test kit, which was recommended to and delivered to the FAA.

14. SUBJECT TERMS
night vision goggles, compatible cockpit lighting, FAA, ANVIS, NVG, visual acuity, NVIS

15. NUMBER OF PAGES
27

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassifed	Unlimited

THIS PAGE IS INTENTIONALLY LEFT BLANK

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the excellent statistical analyses provided by Charles Goodyear and the outstanding technical support of Sheldon Unger and David Sivert, all of General Dynamics, Inc., Dayton, OH.

THIS PAGE IS INTENTIONALLY LEFT BLANK

INTRODUCTION

Cockpit lighting can interfere with the proper operation of night vision goggles (NVGs) in several specific ways. For each interference mechanism, the effect on the image seen through the NVGs is to reduce the light level or contrast of the useful image (the view outside the aircraft). This reduction in light level or contrast can be manifested as a reduction in visual acuity and/or as an observed loss of contrast or brightness. The currently accepted practice for making a final determination of the compatibility of a lighting system with NVGs is to compare visual acuity through the goggles with and without the cockpit lighting activated. The currently employed procedure was developed by the military and requires relatively expensive illumination sources and radiometric measurement equipment (greater than $60K) plus highly trained personnel to conduct the test. In addition, the military method has not been validated for repeatability or reproducibility. The problem is how to achieve the same level of Night Vision Imaging System (NVIS) field assessment results without using expensive equipment. In order to determine if the cockpit lighting interferes with the proper operation of the NVGs, a field evaluation kit was developed and can be used to implement the NVG visual acuity performance assessment procedure as described, herein.

BACKGROUND

Civilian interest and use of NVIS technology is increasing. The RTCA organized a special committee (SC-196) to address the area. One method for determining NVIS acceptability has been described in the draft Minimum Operational Performance Standards document created by this committee. The procedure is patterned after the method developed by the military, which uses relatively expensive equipment. As civilian use of NVGs increases, the FAA will be confronted with unverified alternative assessment methods by applicants who cannot afford this expensive equipment. If the FAA has access to verified, inexpensive, alternative methods, this problem will be mitigated. AFRL/HECV was requested by the FAA to investigate low-cost alternative methodologies that can be used by civil aviation to evaluate cockpit lighting compatibility with the proper operation of NVGs. This research effort was jointly funded by the FAA (Washington, DC) and AFRL/HECV (Wright-Patterson AFB, OH).

OBJECTIVE

The objective of this effort was to devise inexpensive, alternative methods to accomplish a final NVIS field evaluation that is as accurate and repeatable as the currently accepted military method, which uses expensive calibrated illumination sources and radiometric measurement equipment. The final methodology is based on the use of significantly less expensive equipment.

APPROACH

An inexpensive alternative method to assess compatibility, that provides the same quality of results as the accepted military method is needed for civilian applications. Several

technical approaches were investigated for this effort. The first part of this project successfully investigated equipment, methods and procedures that could result in an acceptable, inexpensive alternative method. A visual acuity method using an inexpensive illuminator, validated with an inexpensive illuminance meter, was devised and successfully demonstrated in a human use study.

In order to test the different approaches, a simple cockpit lighting simulator was built. The simulator allowed tight control over the NVIS lighting levels and lighting geometry. The simulated cockpit consisted of adjustable "cockpit lighting", a transparency for viewing through, and a glare shield. Since the accepted military technique has not been tested for repeatability and reproducibility, it was necessary to devise a means to accomplish this test, too. To this end, a laboratory-level simulation of an NVIS cockpit was fabricated and evaluated with the existing military-approved evaluation methodology. This simulated cockpit included a means to adjust the level of compatibility (e.g., by changing cockpit lighting NVIS radiance level without changing the luminance level) and the reflective lighting geometry. Please refer to the reports to the FAA reprinted in their entirety in Appendices C and D for the specific study details.

RESULTS

The following sequence of steps describe the basic results of this research effort, which uses the NVIS Lighting Evaluation Kit (developed as part of this effort) to determine whether a cockpit lighting system is compatible with Night Vision Goggles (NVGs).

Step 1. NVG Verification
Verify that the NVGs being used meet the minimum visual acuity requirements at specified light levels by consulting the SC-196 RTCA Special Report (2001). For additional information on NVG compatible cockpit lighting, see Pinkus, Task, Dixon, Barbato & Hausmann (2003).

Step 2. Test Facility Verification
Verify that the test facility is dark enough to perform the NVG/cockpit lighting compatibility evaluation by conducting the following test:

a. Within the darkened test facility, position the mounted USAF 1951 tri-bar chart 20 feet from the objective lens of the goggles and illuminate the chart with sufficient light to make it easily visible through the NVGs. See Appendix B for instructions on how to build the illuminator.

b. Focus the eyepiece and objective lenses of the NVGs while viewing the tri-bar chart through the NVGs.

c. Once the goggles are focused, turn off ALL of the lights in the testing facility.

d. Dark-adapt for at least five minutes.

e. With the lights off, view the tri-bar chart and determine the smallest Group and Element number of tri-bars (*must see both the vertical and the horizontal lines*) that can be resolved, if any.

f. If you are not able to resolve a Group and Element smaller than Group −4 (minus 4), Element 1 in the correct orientation, then the facility is dark enough to conduct the lighting evaluation. For an example of the tri-bar chart, see Appendix A.

g. If it is determined that the testing facility is not dark enough for the evaluation, recess the tri-bar chart in a box to shade it from ambient illumination and then re-check to insure that the "dark enough" criterion stated above is met.

Step 3. Procedure for Setting the Distance from the Target to the Illuminator
To insure the correct irradiance level after the "dark enough" criterion has been met, set the distance from the tri-bar chart to the illuminator using the following procedure.

a. Position the light sensor of the illuminance meter 12.0 inches from the front of the baffle of the light source (See Figure 1). Note: This distance is critical, so be as accurate as possible. Steps "a" through "c" are required to compensate for differences in amount of light output from different bulbs.

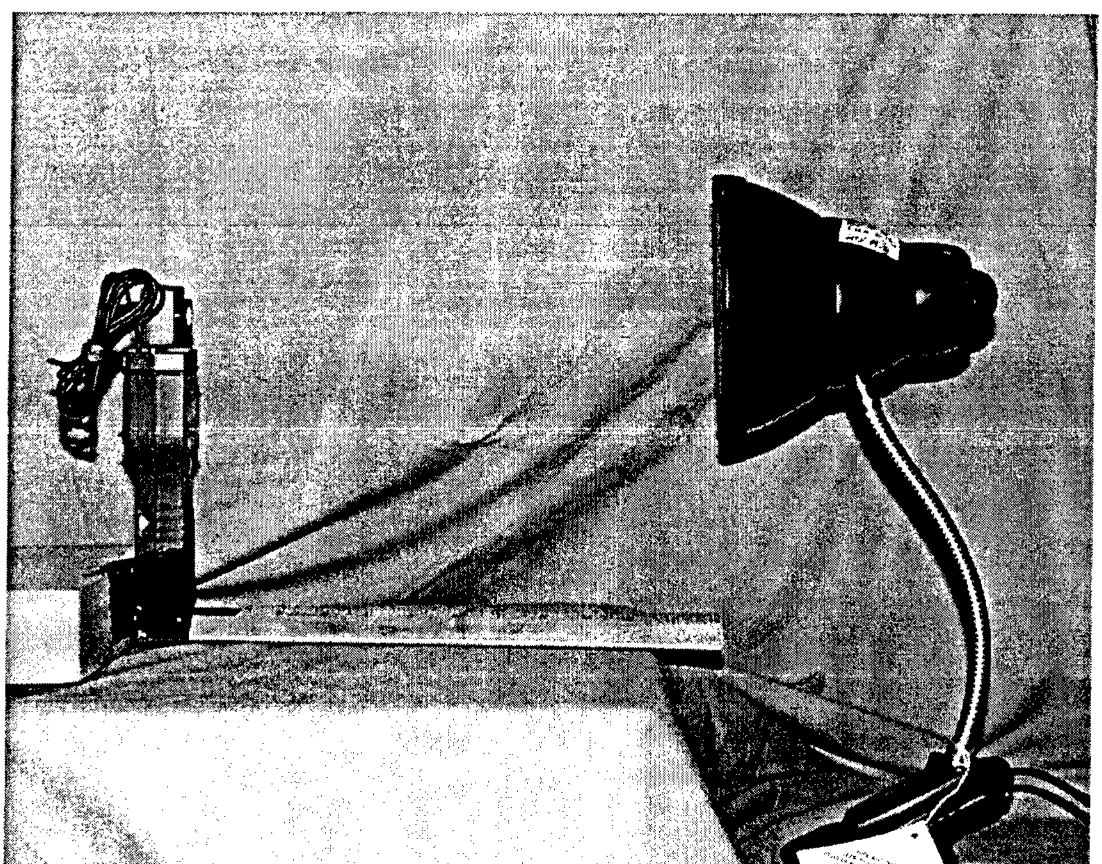

Figure 1. Setup for Determining Distance from the Target to Illuminator

b. Set the switch to the lux position and record the reading.

c. Locate the lux value in the first column of the Distance Look-up Table (Table 1, below). The distance from the target to the illuminator should be set to the distance determined by the look-up chart for the corresponding lux value.

d. Position the illuminator the indicated distance from the target pattern and insure that the target is centered in the illuminated area. Position the objective lens of the NVGs 20 ft from the tri-bar chart.

Table 1. Distance Look-Up Table

	DISTANCE		
Lux at 12 in.	**Decimal (ft)**	**Feet**	**Inches**
0.08	14.48	14	5 ¾
0.09	15.35	15	4 ¼
0.10	16.18	16	2 ¼
0.11	16.97	16	11 ¾
0.12	17.73	17	8 ¾
0.13	18.45	18	5 ½
0.14	19.15	19	1 ¾
0.15	19.82	19	9 ¾
0.16	20.47	20	5 ¾
0.17	21.10	21	1 ¼
0.18	21.71	21	8 ½
0.19	22.31	22	3 ¾
0.20	22.89	22	10 ¾
0.21	23.45	23	5 ½
0.22	24.01	24	0
0.23	24.55	24	6 ½
0.24	25.07	25	¾
0.25	25.59	25	7
0.26	26.10	26	1 ¼

Step 4. Obtain Baseline Visual Acuity

While the observer is sitting in the cockpit with the objective lens of the goggles 20 feet away from the chart (with the chart illuminator turned ON), turn OFF the cockpit lighting. Determine the observer's visual acuity by having the observer identify the smallest Group and Element number on the chart that they can resolve. The observer *must resolve both the vertical and the horizontal bars* in the element. Record the Group and Element number.

Step 5. Obtain Test Visual Acuity
Turn the cockpit lighting ON and determine the observer's visual acuity by having them identify the smallest Group and Element number on the chart that they can resolve. Again, the observer *must resolve both the vertical and the horizontal bars* in the element. Record the Group and Element number.

Step 6. Assessment
If there is no decrement in visual acuity between Steps 4 and 5 (cockpit lighting OFF vs. ON), then the lighting system is NVG compatible. There is a decrement in visual acuity if the Group and Element tri-bar that can be resolved with the lights ON is bigger than the Group and Element number that can be resolved with the lights OFF.

Step 7. Repeat steps 4 through 6 for different view angles through the windscreen / canopy as necessary.

Step 8. Correction of Identified Interfering Light Sources
If there is a decrement in visual acuity between steps 4 and 5, try to locate the source(s) of the offending lights in the cockpit and correct their deficiency. After the deficiency has been corrected, again determine whether there is a loss of visual acuity with the cockpit lights ON compared to OFF.

Step 9. Reflections in the Windscreen/Canopy
If reflections of the cockpit instruments/displays are visible in the windscreen/canopy, move the tri-bar chart and illuminator so the observer is looking through the reflections with the NVGs (if possible). Again, determine if there is a loss of visual acuity with the cockpit lights ON compared to OFF.

REFERENCES

RTCA/DO-275, 12 October 2001. *Minimum operational performance standards for integrated night vision imaging system equipment*, prepared by SC-196, Washington, DC.

Pinkus, A. R., Task, H. L., Dixon, S. A., Barbato, M. H. & Hausmann, M. A. (2003). *Twenty-Plus Years of Night Vision Technology: Publications and Patents From the Crew System Interface Division of the Air Force Research Laboratory at Wright-Patterson Air Force Base, Ohio.* (Report No. AFRL-HE-WP-TR-2003-0048). Wright-Patterson AFB, OH: Air Force Research Laboratory.

APPENDIX A

Alternative Visual Acuity Chart Fabrication

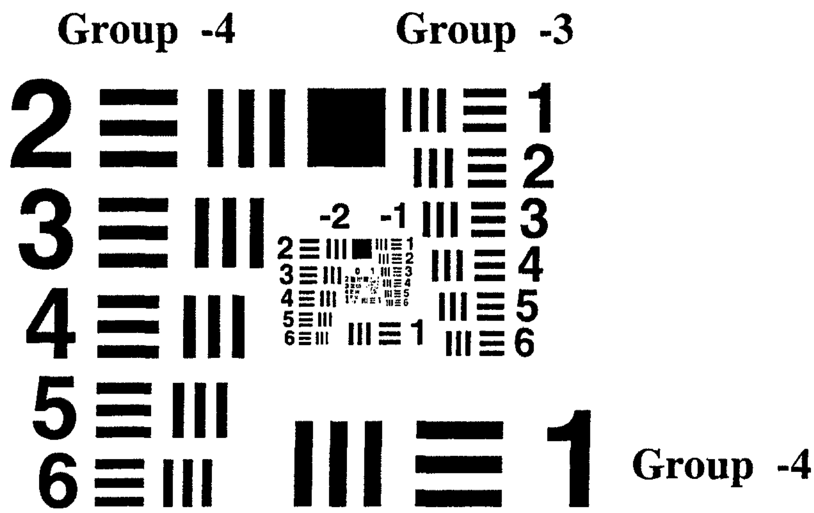

Figure A-1. USAF 1951 Tri-Bar Chart

Source of Tri-Bar Chart: A medium and a high contrast USAF 1951 Tri-bar chart (Figure A-1) is provided on the enclosed CD. A .pdf (Portable Document Format) and a .jpg (Joint Photographic Experts Group) file is provided for both contrasts.

Printer Recommendations: Using a laser printer, print the .pdf file such that Group–4, Element 1 measures 40mm x 40mm (the size of the square defined by the 3 dark and 2 light bars).

Paper Recommendations: 8.5"x11", 87 brightness, 20 lb. weight or equivalent.

Procedure for Mounting Chart to Foam-Core Backing:

- Use a spray adhesive to mount the printed chart to a piece of foam-core.
- When dry, trim the foam-core to the size of the paper

Explanation and Key for converting tri-bars to visual acuity

NVG-aided visual acuity data are obtained using a USAF 1951 Resolution Resolving Power Target (tri-bar) chart. The chart consists of a large number of target elements, encompassing a wide range of sizes, divided into groups of six. The elements progressively increase in size (decreasing in spatial frequency) at relative intervals of $\sqrt[6]{2}$ (approximately 12%). Each element contains two patterns, each composed of three dark lines and separating white spaces, all of equal width; one pattern is horizontal and the other vertical. Each group is identified by a different number, while the elements in each group are numbered 1 through 6. For a given viewing distance, the group/pattern numbers correspond to known Snellen visual acuity values (i.e., 20/20, 20/25, 20/45 etc.).

Table A-1. Conversion of Tri-Bars to Visual Acuity at a 20 Foot Distance (20/XX)

GROUP	ELEMENT	VISUAL ACUITY
-4	1	90.3
-4	2	80.4
-4	3	71.7
-4	4	63.8
-4	5	56.9
-4	6	50.7
-3	1	45.1
-3	2	40.2
-3	3	35.8
-3	4	31.9
-3	5	28.4
-3	6	25.3
-2	1	22.6
-2	2	20.1
-2	3	17.9
-2	4	16.0
-2	5	14.2
-2	6	12.7
-1	1	11.3
-1	2	10.1
-1	3	9.0
-1	4	8.0
-1	5	7.1
-1	6	6.3

Recommended Directions to Evaluators:

- Place the chart 20 feet from the objective lenses of the NVGs worn by the observer seated in the cockpit.
- Ask the observer to determine the smallest Group and Element of tri-bars (*must see both the vertical and the horizontal lines*) that can be resolved.

APPENDIX B

Alternative Visual Acuity Chart Illuminator Fabrication and Use

Light Source Components:

Gooseneck Metal Clip On Lamp (See Figure 1)
7.5 watt bulb (See Figure B-1)
6" Round Damper Baffle (See Figure B-2)

Figure B-1. 7.5 watt bulb

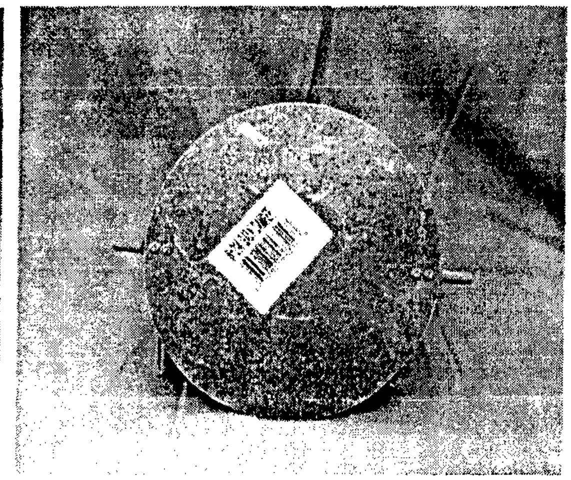

Figure B-2. Six in. Round Damper Baffle

Equipment and Materials Needed for Fabrication:

Drill
⅛" drill bit
Hammer
Common Nail
Pencil
Small flat file
Ruler with 32nd inch divisions
Flat black spray paint
Black masking tape

Fabrication Instructions (See Figure B-3):

- Unpack all equipment.
- Insert 7.5 W bulb into the lamp and check for operation.
- Remove the mounting screws on the sides of the damper baffle by drilling out the rivets on the mounting bracket screws with a drill and ⅛" bit.
- Locate the center of the 6" baffle with a ruler.
- Mark the center with a pencil.
- Make a punch mark in the center of the baffle using a hammer and a nail.
- Drill a ⅛" hole in the center of the damper baffle.
- Use the metal file to remove sharp metal edges of the drilled hole.
- Paint the baffle on both sides with flat black spray paint.

- Use the black tape to cover the holes in the lamp housing to prevent light leaks.
- Center the baffle over the opening of the lamp.
- Use black tape to secure the baffle to the bell of the lamp housing.

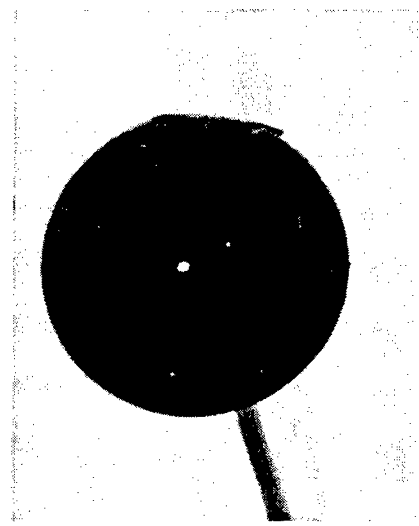

Figure B-3. Modified Lamp/Illuminator

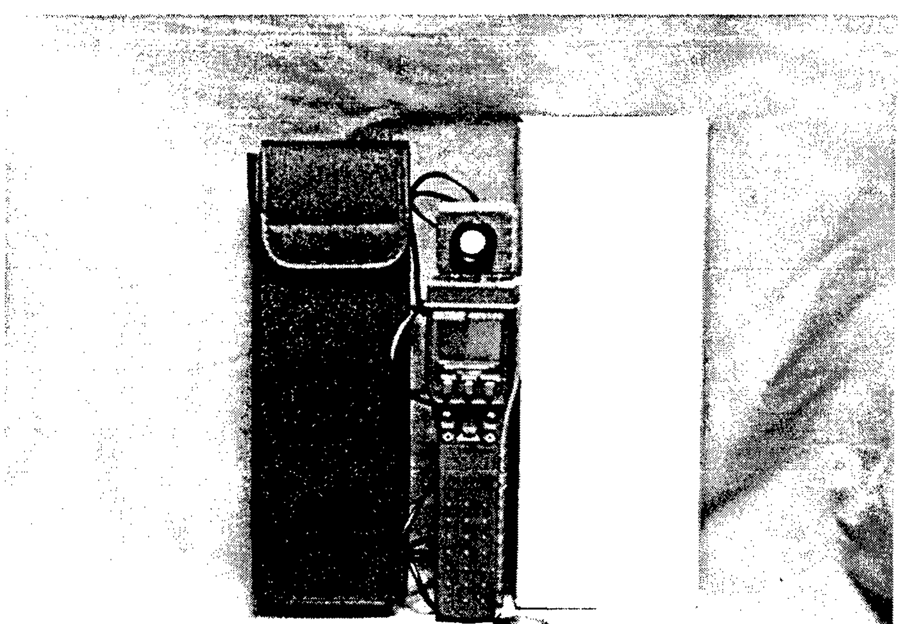

Figure B-4. Light Meter with a Detachable Sensor / Probe

Illuminance Meter:
Light Meter (See Figure B-4)

APPENDIX C

First report issued to the FAA: Aviation Maintenance, General Aviation, and Vertical Flight Human Factors. Washington DC (2003).

NIGHT VISION IMAGING SYSTEM
LIGHTING COMPATIBILITY ASSESSMENT METHODOLOGY

[*]H. Lee Task, Ph.D., [§]Alan R. Pinkus, Ph.D., [†]Maryann H. Barbato, [†]Martha A. Hausmann
[*]Task Consulting, Dayton, Ohio
[§]Air Force Research Laboratory, Wright-Patterson AFB, Ohio
[†]Sytronics, Inc., Dayton, Ohio

Aircraft cockpit lighting can interfere with the proper operation of night vision goggles (NVGs). Methods to verify compatibility between cockpit lighting and NVGs involve expensive equipment. An inexpensive alternative method to assess compatibility, that provides the same quality of results, is needed. Since the quality of the existing lighting compatibility methods has not been studied, it was necessary to determine the quality of existing methods and compare them to alternative methods using a night lighting simulator. The visual acuity-based evaluation method is relatively imprecise, but it can be implemented using alternative, inexpensive equipment and techniques. An alternative evaluation method, that makes use of the light output of the NVGs, looks promising. It provides a more precise acceptance/rejection criteria than the visual acuity method.

INTRODUCTION

Night vision goggles (NVGs) amplify and convert available ambient light at night to produce an image viewable by the observer that is hundreds or thousands of times brighter than the same scene viewed with the naked eye (see Fig. 1). Current NVGs used for flight are sensitive to wavelengths from about 625 nm or 665 nm (depending on objective lens coating) to about 900 nm. Unfortunately, most unmodified aircraft cockpit lighting emits considerable energy in this wavelength range that can make it very difficult or impossible to see through the windscreen with the NVGs.

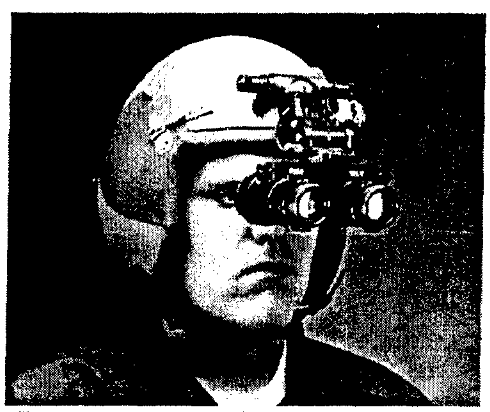

Figure 1. F4949 night vision goggles

Unmodified aircraft cockpit lighting can interfere with the proper operation of NVGs in several specific ways. For each interference mechanism, the effect on the image seen through the NVGs is a reduction of the light level or contrast of the view outside the aircraft. This reduction in light level or contrast can be manifested as a reduction in visual acuity and/or as an observed loss of contrast or brightness. Many techniques have been developed to produce cockpit lighting, including instrumentation and displays, that are reasonably compatible with the operation of NVGs[1]. *Reasonably compatible* means there is sufficient light for the pilot to view his/her instruments and displays (note, pilots look under the NVGs to directly view their instruments) but the lighting is such that it does not significantly interfere with the image of the exterior scene viewed through the NVGs.

The US Air Force, Army, and Navy have pursued the use of NVGs for piloting aircraft for over 20 years. One of the first major issues to be addressed was cockpit lighting compatibility with the NVGs.[2] The military eventually developed a criteria that could be relatively easily, but not inexpensively, implemented to determine whether or not the cockpit lighting was night vision imaging system (NVIS) compatible. These criteria have been expanded considerably from their original concept and are documented in various publications[1,3,4,5,6,7]. The original basic concept was that no lighting source in the cockpit, when adjusted to the specified luminance level, should appear brighter through the NVGs than tree bark illuminated with natural clear starlight[7]. This concept was converted to photometric and radiometric criteria for various cockpit lighting sources. For example, electronic displays adjusted to produce an output luminance of 0.5 foot-Lamberts should not exhibit an NVIS radiance greater than 1.7×10^{-10} watts/cm^2-sr. The NVIS radiance is the radiance of the display as weighted by the spectral sensitivity curve of the NVGs. There are currently two published spectral sensitivity curves for NVGs used in flight, designated NVIS A and NVIS B. NVIS A spectral sensitivity starts at about 625 nm and NVIS B sensitivity starts at about 665 nm.

Although this approach provides easy to understand criteria for passing or failing a lighting system for NVIS compatibility, it also requires the use of expensive equipment to accurately measure the luminance and NVIS radiance values of the various light sources. Since this equipment is not conducive to a field assessment of NVIS compatibility, there is a secondary approach that is used, based on visual acuity, that is described in the various military publications.[3] In this secondary approach, a trained evaluator sits in the cockpit of the aircraft while it is located in a dark, light-controlled hangar. A visual acuity chart (e.g., USAF 1951 Tri-bar Resolution Chart) is positioned 20 feet from the objective lens of the NVGs and illuminated to an NVIS radiance of 1.7×10^{-10} watts/cm^2-sr (tree bark in clear starlight). The cockpit lighting level is adjusted to an *operational level* so that it is easily visible to the evaluator. The evaluator then determines his/her visual acuity with the cockpit lighting system on and off. If there is any decrement in visual acuity between the on and off conditions, then the lighting system is considered unacceptable. If there are any reflections noted in the aircraft windscreen, then the visual acuity chart is to be repositioned, if possible, so that the evaluator is viewing directly through the reflection.

There has been essentially no research to determine the repeatability and/or reproducibility of either the NVIS radiance measurement method or the visual acuity assessment method of determining NVIS lighting compatibility. The primary objective of the research described herein was to develop an inexpensive NVIS lighting methodology that would produce essentially the same or better results than the documented military assessment techniques[8]. Particular emphasis was placed on the visual acuity approach, since it is the most often used method for performing a field assessment of cockpit lighting. It was therefore necessary to assess how good the currently used visual acuity method is and what other possible methods could be used to achieve equivalent or better results.

APPROACH

In order to develop an alternative method for the visual acuity-based approach, it was necessary to identify the specific elements of the method and produce inexpensive alternatives. The specific elements identified for devising alternatives were: 1) the visual acuity chart, 2) the calibrated illuminator, 3) a means of verifying the chart radiance, and 4) a means of determining that the test facility is sufficiently dark to conduct the test.

Several alternative methods to the visual acuity-based method were discussed and documented. One of these was selected for inclusion in the study.

In order to evaluate different NVIS compatible lighting assessment methodologies, it was necessary to devise a night lighting simulator (NLS) so that numerous assessments could be conducted under various controlled conditions.

VISUAL ACUITY METHOD ELEMENTS

Visual Acuity Chart: The baseline military method[6] uses a commercially available USAF 1951 Tri-bar resolution chart (medium or high contrast) that costs approximately $600. The alternative method chosen uses a PDF file of the USAF 1951 Tri-bar resolution chart that was located on the World Wide Web. The chart was laser printed on 8.5 x 11-inch white bond paper and mounted to a foam core back. Photometric and radiometric measurements of the alternative chart verified that it was comparable to the commercially available chart.

Illumination Source: The baseline military method uses a commercially available, calibrated illumination source that costs approximately $5000. The alternative method uses an inexpensive goose-neck lamp. A baffle with a 1/8 inch diameter hole covers the open end of the lamp housing. When the 7.5-watt light bulb is powered by 115 VAC, it provides approximately the correct irradiance at 20 feet. To correct for variability in line voltage and lumen output differences among light bulbs, an inexpensive ($150) illuminance meter was used. An empirically derived look-up table was used to adjust the chart-to-illuminator distance, in order to achieve the correct NVIS irradiance.

Verification of Illumination Level: The baseline military method makes use of two different NVIS radiance measurement devices (approximately $20,000 and $28,000) to verify the NVIS radiance of the white background of the chart. The alternative method verifies the light level by making use of the illumination meter, noted above, and the look-up table.

Test Facility Light Level: The baseline military method makes use of the NVIS radiance measurement equipment to verify that the facility is dark enough to conduct the test. The alternative method is to use the inexpensive visual acuity chart and verify that the evaluator, when looking through the NVGs, cannot resolve the largest pattern on the chart (20/90.3 Snellen acuity).

EVALUATION COMPARISON STUDY

Introduction: Although there are several mechanisms by which cockpit lighting can affect the NVGs, only two basic conditions were selected to be studied. These two conditions were: 1) a uniform light source (display) reflecting in the windscreen, and 2) a uniform display that is blocked by a glare shield from reflecting in the windscreen but may still be within the NVG field of view. The NLS was designed to produce these two conditions and provide a selectable level of NVIS radiance compared to visible luminance. Using the NLS, three different assessment

approaches were studied: 1) visual acuity decrement, 2) direct radiance measurement, and 3) NVG luminance output level measurement.

Observers: Six males and four females ranging in age from 23-51 participated in this study. Prior to participation in the study, all observers underwent a visual examination to insure they had normal or corrected acuity of 20/20 or better.

Apparatus: The lighting simulator (see Fig. 2) was positioned directly in front of the observer. The visual acuity chart was positioned 20 feet from the objective lens of the NVGs and illuminated with an incandescent lamp. The NVIS radiance on the chart was monitored using a Photo Research 1530AR radiometer. Model F4949C NVGs were used in this study. A Hoffman Engineering NVG 103 radiometer was used by the observers to measure the NVIS radiance of the interfering light source. The actual radiance and luminance of the lighting simulator was measured using an Instrument Systems Model 320 spectral scanning radiometer.

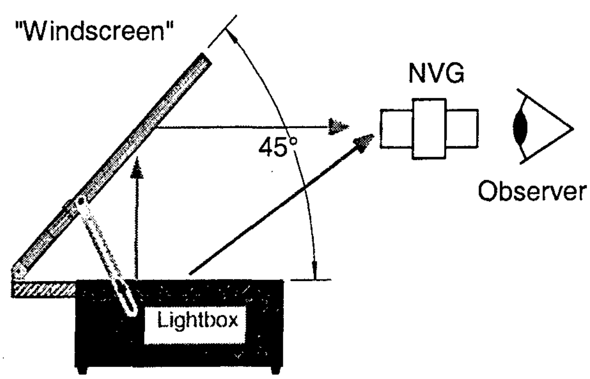

Figure 2. NLS in Reflective Mode

Procedure: Observers were seated behind the NLS and the armrest and seat height were adjusted. Since the NVGs were hand held, the armrest was positioned to allow proper alignment with the stimulus and to reduce fatigue. The room lights were turned off and the observer dark-adapted for 12 minutes. If the session involved the use of NVGs, observers were asked to focus them according to the procedure taught to them during their orientation. Prior to each task, the observer received a sufficient number of practice trials for familiarization with the task and equipment. For the reflected and non-reflected conditions, the following three tasks were counterbalanced. The NVIS radiance light levels were randomly presented for each task.

Task 1: Observers looked through a pair of F4949C NVGs at a USAF 1951 Tri-bar chart. A Photo Research 1530AR was used to monitor the NVIS radiance of the target. The observers identified the group and element number of the smallest pairs of horizontal and vertical bars they could resolve. They closed their eyes between each trial while the experimenter adjusted the NVIS radiance of the NLS. The experimenter instructed the observers to open their eyes and begin the next trial. Five data points were collected per NVIS radiance light level, for a total of 35 data trials for each of the reflective and non-reflective lighting conditions.

Task 2: The observers rested their elbows on the armrest while holding the Hoffman NVG 103. After focusing it, the observer aimed the device so it was perpendicular to the center of the NLS. They adjusted the brightness of the internal test patch located inside the Hoffman NVG 103 to match the brightness of the NLS. Once they were satisfied with their setting, the observers read the digital output on the NVG 103 and the experimenter recorded the data. Ten data points were collected per NVIS radiance level, for a total of 70 data trials for each of the reflective and non-reflective lighting conditions.

Task 3: The observers rested their elbows on the armrest and focused the right ocular of the NVGs. The experimenter attached an Extech Light ProbeMeter to the eyepiece of the right ocular with black masking tape. The observers held the goggles steady while aiming them

through the simulated windscreen at the Tri-bar target. When the NVGs were steady, the observer signaled the experimenter, who then recorded the measurement (lux) from the digital readout of the light meter. The experimenter then adjusted the light level of the NLS and indicated when the next trial was to begin. This procedure was repeated ten times per light level for a total of 70 data trials for each of the reflected and non-reflected lighting conditions.

Results: Figure 3 is a summary of the raw data from one of the ten observers. The two columns correspond to the reflected and non-reflected conditions, respectively, and the three rows correspond to the visual acuity assessment (Task 1), NVIS radiance measurement using the NVG 103 (Task 2), and the NVG output luminance measurement (Task 3), respectively. For each observer, these raw data were converted to acceptance/rejection results and then combined. The visual acuity data were converted to an acceptance/rejection decision by comparing each of the individual's visual acuity data points for both the *off* and *on* cockpit lighting conditions. If the observer's visual acuity was worse for any given *on* condition than for the *off* condition, then that pair of points was scored as a *reject*. If the two acuities were the same or if the *on* condition was actually better than the *off* condition, then it was scored as an *accept*.

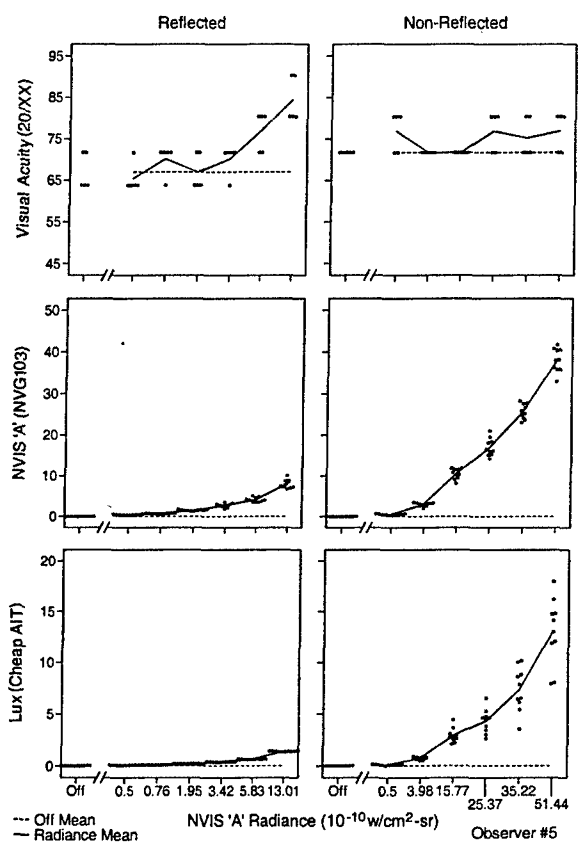

Figure 3. Example of one observer's raw data. Top row is visual acuity data, middle row is NVG 103 data, and bottom row is NVG luminance output data.

This pairing technique produces 25 scores for each NVIS radiance level (five *off* acuities paired with 5 *on* acuities for each radiance). The top row of Figure 4 shows the results of this acceptance/rejection scoring technique for the visual acuity, Task 1.

For the NVG 103 level, the NVIS radiance level of $1.7x10^{-10}$ watts/cm^2-sr was selected as the acceptance/rejection criteria level. For the NVG luminance output, a value of 0.32 was selected,

since that approximately corresponded to the 1.7×10^{-10} watts/cm^2-sr NVIS criteria level determined by empirical measurement.

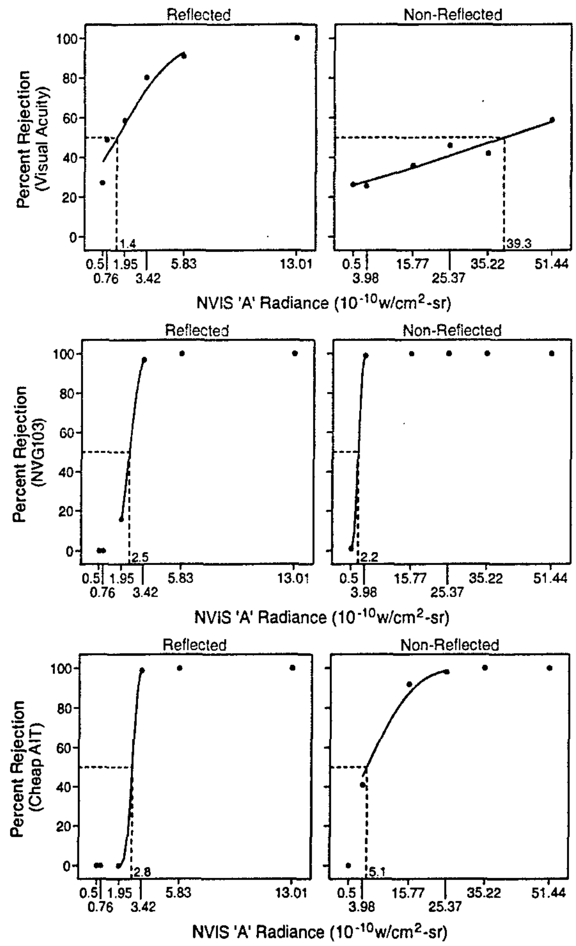

Figure 4. Acceptance/Rejection study results for the two reflection conditions and the three assessment tasks. Vertical axis in each chart is the percentage (or probability) of rejection of the lighting system as incompatible.

Figure 4 is a summary of the percent rejection across all 10 observers as a function of the NVIS radiance levels. Note that the radiance levels used for the non-reflected condition were much higher than for the reflected condition, in an attempt to obtain a visual acuity effect in the non-reflected mode. Sample sizes for each radiance level were as follows: visual acuity task, n = 250; NVG 103 task, n = 100; NVG luminance output task (labeled as "cheap AIT"), n = 100. Probit analysis was used to fit the percent rejections[9]. The dashed lines indicate the estimated NVIS radiance level that corresponds to a 50% rejection probability.

DISCUSSION

Although the 50% rejection probability NVIS radiance values are noted on the six graphs of Figure 4, these values may not depict the most important aspect of these curves. Ideally, one would like an acceptance/rejection criteria that produces a steep curve cleanly separating the acceptance from the rejection regions. The specific NVIS radiance values used were subjectively set by the experimenter to cover the gamut from no visual acuity interference to essentially 100% visual acuity interference. It is apparent in the upper left graph of Figure 4, that the visual acuity

assessment task resulted in a fairly slowly rising curve, even in the relatively tightly controlled reflected condition. For the non-reflected condition, there is certainly a trend toward higher probability of rejection, as the NVIS radiance increases, but the curve is exceedingly wide, indicating a considerable lack of precision.

Another point should be made regarding the visual acuity curves. It appears that the current rejection criterion of 1.7×10^{-10} watts/cm^2-sr is probably not low enough for light sources that reflect in the windscreen but excessively low for light sources that do not reflect in the windscreen.

The middle row of figures illustrates the NVG 103 radiometer data. This device uses an actual image intensifier tube and a brightness matching technique to determine the NVIS radiance. While looking through the device, the user adjusts the brightness of a small internal luminance patch until it matches the brightness of the object of interest. Figure 4 shows that the NVG 103 provides a very sharp rejection criterion when compared to the visual acuity method, even though it is a relatively inaccurate device. It should be noted that this condition was different than the other two. For both the reflected and the non-reflected conditions, the NVG 103 was pointed directly at the light source of the NLS, since the military baseline method ignores the reflection or non-reflection issue.

Figure 4, row 3, illustrates the results of the data collected with the inexpensive illuminance meter (cheap AIT). The concept behind this approach is that the cockpit lighting should add very little light to the output of the NVG image, if the lighting is properly compatible. Since the NVGs, with the attached illuminance meter, were always pointed toward the windscreen of the NLS, the mechanism by which they received light differed between the reflected and the non-reflected conditions. In the reflected condition, the NVGs were amplifying the reflected image of the NLS light source. In the non-reflected condition, some light from the NLS light source could have been imaged directly into the NVGs. This was due to the observer holding the NVGs, such that the NLS light was within the field of view. Nevertheless, the cheap AIT provided a rejection curve that fell between the curve of the visual acuity method and that of the NVG 103.

CONCLUSIONS

Results from the alternate visual acuity assessment study clearly show that NVG cockpit lighting compatibility assessment can be accomplished using inexpensive equipment. It is also evident from Figure 4 that the visual acuity assessment procedure is prone to both Type 1 and Type 2 errors, due to the relatively broad nature of the curve. Furthermore, it is apparent that the NVIS radiance-based criteria, currently used by the military, does not adequately address the difference in visual impact of a reflected light source versus a non-reflected light source.

The NVG 103 provided much better results than the visual acuity assessment, although it does not differentiate between reflected and non-reflected light sources, as noted above.

The NVG light output measurement (cheap AIT) looks very promising as a possible objective method of verifying NVG compatible cockpit lighting. Issues that still need to be addressed, using this device, are calibration procedures and the establishment of a criterion level.

REFERENCES

1. RTCA/DO-275, 12 October 2001. *Minimum operational performance standards for integrated night vision imaging system equipment*, prepared by SC-196, Washington, DC.

2. Task, H. L., & Griffin, L. L. (1982). PAVE LOW III: Interior lighting reconfiguration for night lighting and night vision goggle compatibility. *Aviation, Space & Environmental Medicine, 53*, 1162-1165.

3. ASC/ENFC 96-01 REV 1, 22 March 1996. Interface document, lighting, aircraft, interior, Night Vision Imaging System (NVIS) compatible. Wright-Patterson AFB, OH: ASC ENFC.

4. MIL-STD-3009, 2 February 2001. *Dept of Defense interface standard for lighting, aircraft, Night Vision Imaging System (NVIS) compatible.*

5. MIL-L-85762A, 26 August 1988. *Military specification, lighting, aircraft, Night Vision Imaging System (NVIS) compatible.*

6. Reising, J. D., Antonio, J. C., & Fields, B. (1995). *Procedures for conducting a field evaluation of night vision goggle-compatible cockpit lighting.* (Report No. AL/HR-TR-1995-0167).

7. Reetz III, F. (1987). *Rationale behind the requirements contained in military specs MIL-L-85762 and MIL-L-85762A.* (Technical Report NADC-87060-20). Warminster, PA: Naval Air Development Center.

8. Interagency Agreement DTFA01-02-X-02017 (February 2002) between the Federal Aviation Administration (FAA) and the Department of Defense Air Force Research Laboratory (AFRL/HEC, Wright-Patterson AFB).

9. Finney, D. J. (1980). Probit analysis (3rd ed.). Cambridge: Cambridge University Press.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the excellent technical support of Sheldon Unger and David Sivert of Sytronics, Inc., Dayton, OH.

APPENDIX D

Final report issued to the FAA: Aviation Maintenance, General Aviation, and Vertical Flight Human Factors. Washington DC (2004).

NIGHT VISION IMAGING SYSTEM LIGHTING COMPATIBILITY ASSESSMENT METHODOLOGY: PART 2

[*]H. Lee Task, Ph.D., [§]Alan R. Pinkus, Ph.D., [†]Maryann H. Barbato, [†]Martha A. Hausmann
[*]Task Consulting, Dayton, Ohio
[§]Air Force Research Laboratory, Wright-Patterson AFB, Ohio
[†]General Dynamics, Inc., Dayton, Ohio

If night vision goggles (NVGs) are to be safely used by pilots, it is necessary that the cockpit lighting and displays be compatible with the operation of the NVGs. The current standard field practice for verifying that cockpit lighting and displays are compatible with the NVGs is to conduct a visual acuity degradation assessment. This method is subjective and, as the research described herein, relatively imprecise. An alternative method is to directly measure the amount of interfering light caused by the cockpit lighting and displays. This is referred to as the NVG light output method or NLO. The research reported here demonstrates the superiority of the NLO method compared to the visual acuity method with respect to objectivity and precision. Although the NLO method still needs some further refinement, it is recommended that this method be adopted as a standard field method for assessing cockpit lighting compatibility.

INTRODUCTION

The study and results described in this document are a follow-on effort to a study that was previously reported[10]. Much of the fundamental introductory material will not be repeated here. Therefore, it is recommended that this report be read in conjunction with reference 10 if the reader is unfamiliar with the basic issues being addressed in this study. Prior work[10] has established the viability of an inexpensive, alternative method of determining whether or not a cockpit lighting system is compatible with the operation of night vision imaging systems (NVIS) such as the night vision goggles (NVGs) shown in Figure 1.


Figure 1. F4949 night vision goggles

Unmodified aircraft cockpit lighting and displays can interfere with the proper operation of NVGs in several specific ways. For each interference mechanism, the effect on the image seen

through the NVGs is a reduction of the light level or contrast of the view outside the aircraft. This reduction in light level or contrast can be manifested as a reduction in visual acuity and/or as an observed loss of contrast or brightness. Many techniques have been developed to produce cockpit lighting and displays that are reasonably compatible with the operation of NVGs[1]. *Reasonably compatible* means there is sufficient light for the pilot to view his/her instruments and displays (note: pilots look *under* the NVGs to directly view their instruments) but the lighting is such that it does not significantly interfere with the image of the exterior scene viewed through the NVGs.

Phase 1 of this joint research effort[10] between the Federal Aviation Administration (FAA) and the US Air Force Research Laboratory (AFRL/HECV) investigated the visual acuity assessment method using inexpensive equipment as well as an objective method based on NVG light output. The results from this first phase demonstrated that the visual acuity assessment method could be conducted just as well with inexpensive equipment and that the visual acuity method was relatively imprecise when compared to the inexpensive, objective method. The objective method investigated was based on measuring the relative amount of light output increase that was encountered as the cockpit lighting and displays were turned "on" compared to the "off" condition. This extra light output is what would cause interference in the NVGs and thus should be related to the degradation in image quality of the NVG image. For simplicity, this objective method will be referred to as the NVG light output method or NLO method.

Although the results of the first phase of this joint effort were quite encouraging regarding the use of inexpensive equipment for assessing NVIS lighting compatibility for both the visual acuity (VA) and the NLO methods, there were three issues that needed to be resolved. The first issue related to the basic method of the study. In this first study, subjects viewed the visual acuity chart through the NVGs for six different NVIS radiance levels, plus lights off. These seven levels were presented randomly to make the study more objective. The current practice in the field is to look at the VA chart with lights "off" immediately followed by lights "on" to make it easier to compare the two conditions. Therefore the first study did not exactly duplicate what is currently done in the field, but rather used a procedure that was slightly more objective.

The second issue deals with the NLO method. This method uses an inexpensive illuminance meter taped to the eyepiece lens of the NVG so that a light reading is obtained that is proportional to the average scene luminance of the NVG image. Subjects were instructed to point the NVGs with the attached light meter through the simulated windscreen just as if they were looking through the NVGs at the visual acuity chart; only the illuminator for the VA chart was not on. Since there was no precision in pointing the NVGs through the simulated windscreen, it was possible that some of the field of view of the NVGs could contain the image of the cockpit lighting simulator, which could lead to a higher amount of variance in the NLO readings for the same NVIS radiance conditions.

The third issue has to do with selecting a "compatibility cut-off" level for the NLO method. Because of the relatively low light output level of the NVGs, the diffuser on the illuminance meter had to be removed to provide increased sensitivity. This means the light output is not calibrated to any specific, accepted photometric units. Since NVGs can vary in their maximum light output and in their gain values, some type of relative value (relative to the specific NVG used) must be established for acceptance/rejection criteria.

Resolving these three issues was the primary goal of the current research reported in this document. Issue one was addressed by presenting subjects with consecutive "off" then "on" conditions to accurately simulate the current field method. For issue two, subjects were instructed to look through the other ocular of the NVGs and make sure that no part of the cockpit lighting simulator that was emitting light was within the field of view of the NVGs. The third issue was resolved by determining the light meter reading when the NVGs were at their maximum output luminance. Then the criteria level would be a fixed fraction of this maximum light output level (e.g., 1% or ½%). This would insure that the amount of interfering light is a

small fraction of the total NVG image light. This value was selected *ex post facto* to correspond to some other currently accepted criteria level dealing with visual acuity loss or NVIS radiance level. This is explained more fully in the analysis and discussion sections.

As in Phase 1, the primary results of this study are a collection of "probability of rejection" curves that graph the probability of rejecting the lighting system, because it is incompatible, against the NVIS radiance level.

APPROACH

The currently accepted visual acuity-based NVIS lighting evaluation method (henceforth called the "VA baseline method") was the baseline for this study. In order to determine if the NLO method was as good as the VA baseline method, some means needed to be devised to characterize the *goodness* of these methods so that they can be compared. Since the primary objective of doing an NVIS lighting evaluation is to make a pass/fail determination as to the compatibility of the NVIS lighting, it was possible to develop a probability of rejection (i.e., failure) of the lighting system as a function of the NVIS lighting radiance level, which is the basic criteria stated in the military specifications. For each NVIS radiance level, the study provided repeated measures of "accept" or "reject" for each subject and the two evaluation methods. These repeated measures could be directly converted to a probability of pass or fail and graphed against the NVIS radiance level, thus producing the probability of rejection curve. Ideally, one would like this curve to be flat at 0% from an NVIS radiance level of zero out to some NVIS radiance level which marks the boundary between acceptable and unacceptable, and then the curve would shoot up to 100% just past that critical NVIS radiance level. If the curve gradually increases as a function of NVIS radiance then it indicates the method is relatively imprecise and prone to Type I and Type II errors (rejecting something that should have been accepted and accepting something that should have been rejected). Therefore the slope of the probability of rejection curve at the 50% probability point can be used as a measure of the precision of the evaluation method, one measure of the *goodness* of the method.

Two basic interference conditions were investigated: 1) light was reflected in the windscreen and 2) light was blocked from reflecting in the windscreen. The first condition causes a veiling luminance from the reflection and the second condition may cause a veiling luminance from light scatter within the objective lens of the NVGs. A total of six NVIS radiance levels were used for each of the two interference conditions (the levels were different for the two conditions because it required much more NVIS radiance to induce interference in the non-reflected mode versus the reflected mode). Each subject was presented with 10 trials for each NVIS radiance level, condition, and evaluation method. A trial consisted of a baseline measurement (either visual acuity or NVG light output) with the simulated cockpit lighting "off" and then a test measurement with the simulated cockpit lighting "on." This resulted in a total of 120 data points per subject (10 trials, six radiance levels, two interference conditions).

METHOD

Subjects: Three males and three females, ranging in age from 40-53, participated in this study. Prior to participation in the study, all observers underwent a visual examination to insure they had normal or corrected acuity of 20/20 or better.

Apparatus: A basic cockpit lighting simulator (NVIS lighting simulator or NLS) was used to recreate the lighting interference conditions and the aircraft windscreen and glare shield. The USAF 1951 Tri-bar chart was used to measure visual acuity, and was illuminated using a calibrated incandescent lamp. The NVIS radiance on the chart was monitored using a Photo Research 1530AR radiometer. Model F4949C NVGs were used in this study. An Extech Light ProbeMeter was attached to the NVGs to measure the luminance output of the goggles. The

actual radiance and luminance of the lighting simulator was measured using an Instrument Systems Model 320 spectral scanning radiometer. For this study, the lighting simulator was configured in either a reflected or non-reflected mode.

Procedure: Subjects were seated behind the NLS and the armrest and seat height were adjusted. Since the NVGs were hand held, the armrest was positioned to allow proper alignment with the stimulus and to reduce fatigue. The room lights were turned off and the subject dark-adapted for 12 minutes. The subjects were then asked to focus the NVGs. For the reflected and non-reflected conditions, the following two tasks were counterbalanced. The NVIS radiance light levels were randomly presented for each task.

Task 1: With the NVIS lighting "off," subjects looked through a pair of F4949C NVGs at the Tri-bar chart and identified the group and element number of the smallest set of horizontal and vertical bars they could resolve. The lighting was then turn "on" and the subjects determined if there was a change in the group and element number they could resolve. Subjects closed their eyes between trials while the experimenter adjusted the NVIS radiance of the NLS.

Task 2: An Extech Light ProbeMeter was taped to the eyepiece of the right ocular of the NVGs using black masking tape. With the NVIS lighting in the "off" position, subjects viewed through the left ocular of the NVGs to aim the NVGs through the windscreen. The experimenter recorded this baseline reading then switched the NVIS lighting "on" and recorded the baseline plus interference reading. NVIS radiance conditions were presented in a randomized order.

RESULTS

Although the individual subject data are of extreme interest due to some individual differences, there is insufficient space in this report to include those data. Figures 2 and 3 show the composite probability of rejection curves for all six subjects for the VA baseline method and the NLO method, respectively, for each of the two interference conditions (reflected mode and non-reflected mode). The graphs shown in Figures 2 and 3, depict the slopes of the curves at the 50% probability level and are summarized in Table 1.

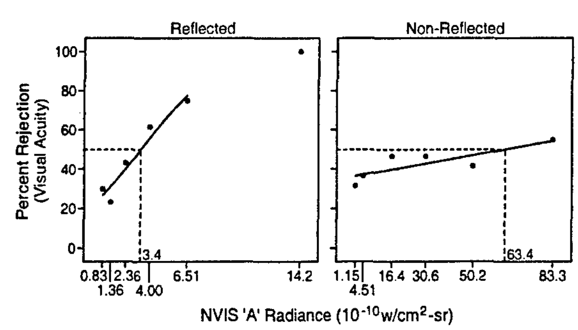

Figure 2. Probability of rejection curves for the VA baseline method for all six subjects combined. The dashed line corresponds to the 50% probability level. Each data point is the average over 60 samples (Six subjects, 10 trials each).

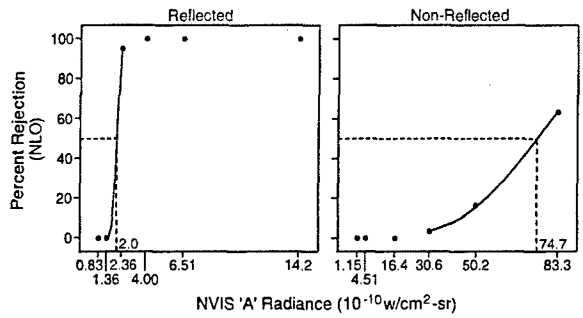

Figure 3. Probability of rejection curves for the NLO method for all six subjects combined. The dashed line corresponds to the 50% probability level. Each data point is the average over 60 samples (Six subjects, 10 trials each).

Table 1. Slopes of the probability of rejection curves at the 50% probability point. Values represent change in percent rejection for a 1 unit (10^{-10}w/cm^2-sr) increase in radiance. The higher the number the more precise the method (less chance of a Type I or Type II error).

Reflected	Visual Acuity	NLO
Yes	9.64	189
No	0.22	1.64

DISCUSSION AND CONCLUSIONS

The visual acuity results of this study, as depicted in Figure 2, are somewhat different than the previous study[10]. The slopes of the reflected mode rejection curves for the two studies are similar but the 50% rejection NVIS radiance point has been shifted by about 50 percent. The reflected mode shifted from a 50% rejection point NVIS radiance of 2.1 in the previous study (after NVIS radiance values of the previous study were corrected) to a 3.4 in the current study. However, the non-reflected mode visual acuity rejection curve did not change by much, shifting from 71.2 in the previous study to 63.4 in this study. The shift in the reflected mode 50% rejection point radiance may indicate that the first issue as discussed in the Introduction Section, regarding having an "off" condition always immediately preceding the "on" condition, did have an effect on the visual acuity "leniency" in allowing a lighting system to pass. From the results, using the 50% criteria point, the current field evaluation method is 50% more lenient (allowing lighting systems with higher NVIS radiance values to pass) as the more objective visual technique that was used in Phase 1.

The most striking results of this study, as in the first study, are apparent from Figures 2 and 3 and Table 1. The NLO method produces a much steeper probability of rejection curve, which means this method is much more precise than the visual acuity method. The technique of making sure the NVIS lighting was not in the field of view of the NVGs (for the non-reflected mode) had a substantial impact on the NLO method results in that it shifted the 50% probability point NVIS radiance from 5.9 in the previous study to 74.7 in this study, which is more in concert with the relatively aimless visual acuity results for the non-reflected mode. This answers the question regarding issue two, described in the Introduction Section, where the NVIS lighting had an unintended affect on the NLO method if it was within the field of view.

The criteria value (what light level reading to use as the demarcation between acceptable and unacceptable lighting) was explored a little bit in this study. The curves shown in Figure 3 used a cut-off value of 0.148 (reading on the light meter), which corresponded to ½% of the maximum light output reading for that NVG. This is a very conservative value and should be investigated in future research.

The main conclusion from these studies is that the NLO method appears to be a very promising objective method of assessing the compatibility of cockpit lighting systems with NVGs. It can be used as a supplement to the visual acuity method or can easily be used to replace the visual acuity method. However, it should be required that a visual inspection of the lighting system, for reflections at particularly objectionable locations, and for light leaks, be performed using NVGs. Another fact that is evident from these studies is the considerable imprecision of the visual acuity method and its corresponding susceptibility to Type I and Type II errors (rejecting a lighting system that should have been accepted and accepting a lighting system that should have been rejected).

It is recommended that the NVG light output method be adopted as a standard, objective method of verifying that the cockpit lighting and displays are compatible with the operation of the NVGs.

REFERENCES

1. RTCA/DO-275, 12 October 2001. *Minimum operational performance standards for integrated night vision imaging system equipment*, prepared by SC-196, Washington, DC.

2. Task, H. L., & Griffin, L. L. (1982). PAVE LOW III: Interior lighting reconfiguration for night lighting and night vision goggle compatibility. *Aviation, Space & Environmental Medicine, 53*, 1162-1165.

3. ASC/ENFC 96-01 REV 1, 22 March 1996. Interface document, lighting, aircraft, interior, Night Vision Imaging System (NVIS) compatible. Wright-Patterson AFB, OH: ASC ENFC.

4. MIL-STD-3009, 2 February 2001. *Dept of Defense interface standard for lighting, aircraft, Night Vision Imaging System (NVIS) compatible.*

5. MIL-L-85762A, 26 August 1988. *Military specification, lighting, aircraft, Night Vision Imaging System (NVIS) compatible.*

6. Reising, J. D., Antonio, J. C., & Fields, B. (1995). *Procedures for conducting a field evaluation of night vision goggle-compatible cockpit lighting.* (Report No. AL/HR-TR-1995-0167).

7. Reetz III, F. (1987). *Rationale behind the requirements contained in military specs MIL-L-85762 and MIL-L-85762A.* (Technical Report NADC-87060-20). Warminster, PA: Naval Air Development Center.

8. Interagency Agreement DTFA01-02-X-02017 (February 2002) between the Federal Aviation Administration (FAA) and the Department of Defense Air Force Research Laboratory (AFRL/HEC, Wright-Patterson AFB).

9. Finney, D. J. (1980). Probit analysis (3rd ed.). Cambridge: Cambridge University Press.

10. Task, H. L., Pinkus, A. R., Barbato, M. H., and Hausmann, M. A. (2003). Night vision imaging system lighting compatibility assessment methodology. *Human Factors Vertical Flight Program Review FY03*, FAA AAR-100, Washington D. C.